PROTOCOL FOR ASSESSING ENERGY PERFORMANCE TO IMPROVE COMFORT CONDITIONS IN SOCIAL HOUSING IN A SPANISH SOUTHERN CITY

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ABSTRACT

Current energy policies focus on cutting on energy consumption in buildings and standardizing the construction process to meet H2020 requirements. Indeed, retrofitting current buildings is a major issue to be addressed. An analysis of the composition of the housing stock is needed to develop any sort of improving action in these buildings. New energy policies that may appear in the following years could benefit from detailed information of the current state of existing residential buildings.

The present paper is aimed to show a protocol to increase and implement the knowledge on social housing current state in southern Spain for further passive energy retrofitting interventions, which could allow for an improvement in indoor conditions too. To this aim, a top-down protocol is proposed to improve comfort conditions in social housing. A first phase corresponding to the creation of a GIS database is used to analyse social housing from an urban scale. Typologies and constructive characterization, energy assessment and a statistical approach is developed. This will allow for the acknowledgement of the most representative social dwellings in the city. A second phase, which corresponds to a dwelling scale, is thought to assess energy performance and the evolution of indoor environmental parameters in the previously selected dwellings, by *in situ* data measures and records, and the energy gradation of the dwellings by means of energy simulation software tools. This analysis will serve to propose integrated passive-energy solutions to retrofit thermal envelopes and to improve comfort conditions in social housing. The mentioned protocol is applied to the social housing stock that was built between 1950 and 1980 in Córdoba, a city from the south of Spain with Mediterranean weather conditions.

Keywords: diagnosis, energy performance, GIS, housing stock, Mediterranean climate

1 INTRODUCTION

A high percentage of existing residential buildings do not comply with minimum energy requirements stated by current energy policies, especially concerning the quality of indoor conditions. To meet H2020 requirements, a standardization of the retrofit process of these buildings to reduce energy consumption [1] is needed. Nevertheless, before taking any action on the current housing stock, an analysis of its composition is needed to foresee any sort of improving strategy in these buildings. Future energy policies could benefit from detailed information of the current state of existing residential buildings.

The analysis of social housing buildings is currently being investigated by many research groups at a national and international level. This work focuses on the Mediterranean area and its singular climate conditions, the energy assessment of the thermal envelope of residential buildings, the study of indoor comfort conditions of the users and the retrofit solutions that eventually will come up.

Some researchers are focused on how to define and classify the existing housing stock regarding building typologies and the energy response associated. These groups analyse the current energy performance of the buildings by developing *in situ* measures, monitoring campaigns, and the definition of the thermal envelope construction systems, to foresee suitable strategies for energy retrofitting with the aim to reduce the energy demand and improve indoor conditions [2]. In a similar climatic context, in Athens, Daskalaki *et al*. [3] developed

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a classification of the residential buildings regarding the typology, as a way of acknowledging how a building responds to energy standards and taking it as a representative sample of a city, a region or a country. European project EEI-TABULA unifies the methods for energy retrofitting that are employed in buildings throughout the European geography. An interactive web platform acts as a consultant regarding the typology, the size of the building and the year of construction [4].

Other researchers committed to improve indoor conditions and reduce energy demand in social housing buildings by acting on the thermal envelope are spread in different areas in Europe, therefore with different climate and environmental conditions [5, 6].

In the field of building energy assessment at different territorial scales, a review on the use of urban building energy models is carried out by Reinhardt and Cerezo [7]. Within the frame of TABULA project, Ballarini *et al.* [8] developed a methodology to address buildings energy deficiencies by a classification regarding typologies and using reference buildings to achieve cost-optimal solutions. Monteiro *et al.* [9] analysed the use of simplified building archetypes to represent different neighbourhood scenarios and calculate their energy consumption. Fracastoro and Serraino [10] run a territorial analysis of primary energy use in buildings by using census data and statistics with the aim to create a methodology that will allow legislators for introducing new energy policies and buildings energy certification procedures. Aiming to achieve H2020 standards and to encourage energy planning policies, Dall'O *et al.* [11, 12], developed a great deal of research at municipal scale in Italy by using cadastre data and large in-field surveys, to evaluate retrofit strategies and address buildings' energy performance, with a Geographic Information System (GIS) database that allows for municipal scale approaches. Caputo *et al.* [13, 14] have worked on the estimation of energy consumption in buildings at urban level with energy models applicable to other cities that foresee the need for a scout tool to monitor the impact of retrofitting measures.

The aim of the present paper and its main contribution is to show a protocol that runs a territorial diagnosis of the current state of existing social housing stock to envisage suitable retrofit interventions to reduce energy consumption and improve indoor comfort as main targets. This protocol is applied to the social housing stock built between 1950 and 1980 in Córdoba, a city from the south of Spain with Mediterranean weather conditions.

2 METHODOLOGY

To reach the aim of the work, a methodology that sets a protocol to improve energy behaviour in social housing from the south of Spain is developed.

2.1 Definition of the approach

The protocol involves the following several phases:

- Identification, classification and selection of social housing neighbourhoods.
- Energy and environmental approach to the existing residential stock from a fixed period.
- Energy analysis of the dwellings chosen as case study.
- Integral retrofitting strategies to upgrade thermal envelopes.

The creation of a GIS database with the geo-location of the social housing stock will help to classify it in typologies, construction systems and energy performance. A statistical approach to the social housing stock from an urban scale will allow for the acknowledgement of the most representative social dwellings attending to their presence in the city.

An energy performance assessment from a dwelling scale will be performed by monitoring some case study samples. The evolution of indoor environmental parameters and the energy gradation of the dwelling with energy simulation software will be developed. This analysis will serve to propose integrated passive-energy solutions to retrofit thermal envelopes and to improve comfort conditions in social housing.

2.2 Scope levels

Three different approaches have been stablished related to the selection and later analysis of the case study samples:

Level 1: it covers the urban level. General characteristics such as name of promotion, number of housing units, year of construction, geo-mapping, etcetera, will be collected from groups over 200 units.

Level 2: it covers the neighbourhood level. Case study buildings will be obtained from a preliminary statistical analysis regarding common typologies and patterns. Case study samples will be documented, to define thermal envelopes, run an energy assessment and an energy grading.

Level 3: it covers the dwelling level. *In situ* tests, energy models' generation and calibration, and an energy and environmental assessment will be applied to case study buildings by means of the simulation software *DesignBuilder* (Energy+). These models will be used for testing energy improvement strategies that will be selected regarding their suitability to the rest of the housing stock previously analysed.

2.3 Sample definition

This phase includes the documentation retrieval for the definition of the area of analysis: first, the location of social housing buildings with over 200 housing units, built within the proposed years; second, a documentation process by consulting Municipal Archive, bibliography and other available sources, as well as visiting the different neighbourhoods. Territorial plans and photographs, memories and additional information will be collected for the development of a level 2 approach.

A GIS database will allow for data organisation, storage, and handling. The information is associated to a single element, that in this case corresponds to a building. An *ad-hoc* GIS software is used [15]. Besides, the available information of the city cadastre and buildings is consulted online [16]. Documentation collected from the available project files is used to complete the database. A statistical approach will be run to define common characteristics of the housing stock.

A matrix that considers building typology, year of construction and façade solutions will allow for the selection of three case study samples that will undergo a level 3 analysis, that is, a deeper insight into the evolution of environmental indoor parameters and comfort conditions.

2.4 Identification, classification and selection of social housing neighbourhoods

This part of the work focuses on the energy context and the expansion of the housing stock in the south of Spain over the years, emphasising its current energy deficiency.

First, the identification of social housing neighbourhoods at a level 1 involves the geo-location of the cases, their classification attending their district, neighbourhood and promotion, location, promotor, year of construction, number of floors and housing units, surface, etcetera, and their collection in a database.

Second, the most common thermal envelope's solutions will be identified and the most representative ones selected. A statistical analysis attending typologies and significance will allow for the selection of case study samples that will undergo a level 3 approach.

Then, a literature review and data collection, involving measures, pictures and necessary information to carry out an exhaustive representation of each case study will be carried out. Eventually, the GIS will allow to organize the data into layers that define the thermal envelope of the buildings, their size, typology and year of construction, among other features.

2.5 Energy audit

2.5.1 Energy audit of the global sample

According to a level 2 approach, an energy analysis will be carried out to have a global idea of the current energy state of social housing. This task involves the collection of quantitative and qualitative parameters from the case study buildings in an environmental, economic and social level. A survey among the users to collect user profiles regarding energy consumption as well as their knowledge about energy use will be developed. Then, the generation of energy models will be done by using *ad-hoc* Spanish official software (*HULC*, *CE3X*). This will grant a first assessment on energy behaviour of the residential stock, covering heating, cooling and global demand, as well as energy grading.

2.5.2 Energy audit for the case study samples

This section describes the set of monitoring campaign and complementary field tests (infrared thermography and air-tightness trials) carried out on the three sample cases.

The monitoring campaign is carried out following UNE-EN ISO 7726:2002 protocol [17] according to similar procedures developed in previous works [18]. Indoor environmental parameters, such as air temperature (T_i), relative humidity (*RH*) and CO_2 concentrations (CO_2), and energy consumption (E_C) are collected. Outdoor weather data was obtained from a weather station. The global audit is planned for collecting data from three different seasons of the year in each case study: winter, mid-season (spring or autumn) and summer, therefore taking a minimum of nine months each.

To complete the assessment of the buildings, two more field tests, such as an infrared thermography study [19, 20] and a depressurization trial [21, 22], were developed, to detect weak points that may force energy loses and air leaks through the outer walls.

3 CASE STUDY

The proposed methodology is applied to a sample from the housing stock built from 1950 to 1980 in Córdoba, a city from the south of Spain.

3.1 Weather data

Outdoor environmental parameters have been obtained from a weather station settled in the campus of the University of Córdoba [23]. Spanish Technical Building Code (CTE) [24] establishes energy requirements of the thermal envelope of buildings attending to several climate zones that depend on the weather severity for a specific location. These climate zones are named with a letter from A to E, which corresponds to a growing scale of winter severity, and a number from 1 to 4, that corresponds to a growing scale of summer severity. According to this, Córdoba is in a B4 climate zone, which means that it suffers from very hot summers, while winters are mild and not too extreme.

3.2 Social housing distribution and case study selection

To assess the territorial distribution of the existing social housing stock in Córdoba, Figure 1 shows the expansion of the city based on the different urban plans developed amongst the years of study. Blue hatches correspond to the expansion between 1956 and 1983, hence corresponding to the construction of most of the existing social housing in Córdoba.

The last national census [25] provides data on the building stock composition at a national and a local level. The distribution of the built housing stock per decade during the last century show a sharp increase in the number of buildings built between 1950 and 1980 in Spain and Córdoba (Figs. 2a and 2b). Figure 2c pictures a similar trend between the national and the

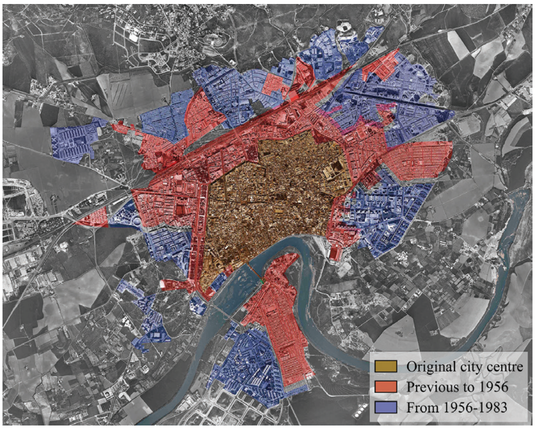

Figure 1: Expansion of the residential building stock in Córdoba from 1950 to 1980.

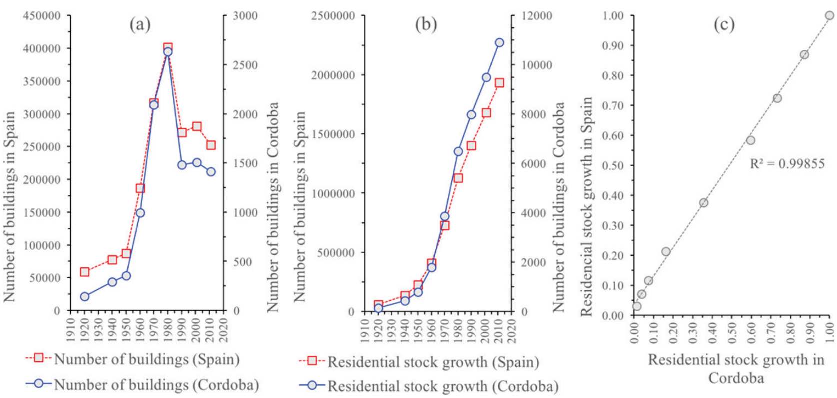

Figure 2: Residential stock figures in Spain and Córdoba from 1900 to 2011. (a) Number of buildings constructed per year; (b) Growth per year; (c) Regression between (a) and (b).

local samples ($r^2 = 0.99$). Hence, the period between 1950 and 1980 is an interesting target to address with the methodology hereby presented both, from a city scale to a country scale.

The analysis of the census' numbers is not enough to understand the composition of the housing stock in Córdoba. The city's neighbourhoods have been spotted and the identification of multi-familiar social blocks has been done to better define the study sample.

The present study only considers multi-familiar buildings over 200 housing units built from 1950 to 1980. The number of social dwellings identified in Córdoba account for 39.26% of the global amount of constructed dwellings between the studied years (Table 1). This percentage corresponds to 19630 dwellings from a total of 50005, according to the National Census. This certifies that Córdoba currently encloses many obsolete social dwellings.

The following parameters have been considered: neighbourhood code, promotion code, name, developer entity, address, year and decade of construction, smallholding surface, constructed surface, number of dwellings and typology. More available information will allow for the definition of the thermal envelopes of the buildings in the GIS database.

For the identified buildings, an energy audit was performed by means of CO_2 emissions, heating and cooling energy demands. To shrink time spent for the audits, the study uses a calculation model called CE3X [26] according to The Basic Document on Energy Saving (DB-HE) [27] of the CTE [24], that offers the current energy behaviour of social housing from 1950 to 1980 in Córdoba.

3.3 Case study buildings definition

Following the methodology, the second phase of the protocol is applied to three different case study housing units that were built between 1950 and 1980. This study is thought to assess the energy performance and the evolution of indoor environmental parameters in three selected flats at a dwelling scale. This is done by collecting *in situ* data measures and an energy gradation of the dwellings by means of *ad-hoc* simulation software. This analysis will serve to propose integrated passive-energy solutions to retrofit thermal envelopes and to improve indoor comfort conditions in social housing.

The case study samples are selected according to their representability in the area, that is, their importance in number and their distribution in the city. The selection is done regarding building typology and façade solution. On the one hand, two main typologies have been found, the 'H-Block' and the 'Linear Block'. The relation between the two types is approximately around 9/1. On the other hand, two main wall solutions have been found, the 'Double-layer brick wall' and the 'Single-layer brick wall', whose relation is approximately around 5/1. Finally, the number of dwellings encompassed in each of the cases selected is an important parameter to be considered. According to the methodology, the selected case study buildings had to involve more than 200 housing units. The chosen promotions for the analysis represent 4375 housing units, which correspond to a 22.28% of the total identified social dwellings in Córdoba and 8.75% of the total housing stock built in the analysed period (1950–1980).

Table 1: Identified residential buildings and housing units built in Córdoba in 1950–1980.

Period of construction	Number of housing units	%
1950–1959	1952	9.94%
1960–1969	9898	50.42%
1970–1980	7780	39.63%

(a) (b) (c)

Figure 3: Case study buildings. (a) Santuario (SA); (b) Parque Figueroa (FI); (c) Parque Cruz Conde (CC).

The three case study samples (Fig. 3) account for the most representative building criteria encountered throughout the housing stock, regarding typologies and wall solutions. Case study 1 (Fig. 3a) is Santuario (named SA) and it has 2000 dwellings. Case study 2 (Fig. 3b) is Parque Figueroa (named FI) and it has 2052 dwellings. Case study 3 (Fig. 3c) is Parque Cruz Conde (named CC) and it has 323 dwellings. Moreover, it is an interesting opportunity to choose three case study buildings that were designed and built by the distinguished architect Rafael de la Hoz, who left a huge modern architectural footprint in the city of Córdoba.

Table 2 offers a definition of the case study buildings in terms of localization, construction, morphological indicators and environmental control systems.

Table 2: Case study buildings definition.

	Case study 1. SA	Case study 2. FI	Case study 3. CC
Year of construction	1972	1968	1967
Typology	H	H	H
Main orientations	NW-SE-NE-SW	N-S-E-W	N-O-SE
No. stories	4	5	5
No. identical blocks	125	108	17
No. units/block	16	19	19
Façade U-value (W/m^{2}K)	SA_1: 1.31	FI_1: 1.47; FI_2: 1.83	CC_1: 1.69; CC_2: 1.12; CC_3: 1.70; CC_4: 2.51
Type of roof	Sloped	Flat	Flat
Roof U-value (W/m^{2}K)	SA_r: 2.29	FI_r: 1.81	CC_r: 1.83
Joinery	Metallic	Metallic	Metallic
Glazing	6 mm (Single)	6 mm (Single)	6 mm (Single)
Window U-value (W/m^{2}K)	SA_w: 5.70	FI_w: 5.70	CC_w: 5.70
Solar protection	No	Yes	Yes
% roof in the envelope	18%	19%	18%
% façade in the envelope	64%	60%	63%
% opening in the envelope	12%	18%	14%
Form ratio (S/V) (m^{-1})	0.49	0.37	0.42
HW production	-	-	-
Ventilation system	Natural	Natural	Natural
Heating system	Stove; split heat pump	Split heat pump	Stove
Cooling system	Split heat pump	Split heat pump	-

4 RESULTS

The analysis of the data compiled in Table 2 displays similarities between the three cases. Morphological indicators show analogous patterns in the three samples, since they have similar height and number of stories. The lack of insulation neither in the façades nor in the roofs, depicts a huge weakness in this kind of buildings. The existent openings are made of single-glazing and a metallic frame with no thermal bridge breaking, which in FI and CC are protected from solar radiation with blinds and awnings. The estimation of U-values in each case show that none of the cases complies with the minimum requirements, sometimes doubling the figures, which rockets the energy demand of the building. Standard U-values are supposed to be up to 1.00 W/m^{2}K for the outer walls and 0.65 W/m^{2}K for the roofs, regarding current Spanish regulation CTE [27].

Figure 4 shows the energy audit of the Southern district in Córdoba at a level 2. With the aim to show a detailed image, only a defined area of the city was selected. Residential buildings included in the energy audit were built between 1950 and 1980. The number of housing units involved corresponds to the 12.69% of the total identified social dwellings in Córdoba and the 4.98% of the total housing stock built in the analysed period (1950–1980).

As a result, the analysed cases display a homogeneous coloured pattern that corresponds to the energy gradation of the buildings from E to G regarding energy consumption and CO_2 emissions (Fig. 4). The energy gradation goes from A to G in a growing scale of energy consumption, being A the best qualified and G the most deficient. This type of diagnosis reflects that a high percentage of current housing stock has a very deficient energy performance, hence needs retrofitting and has a big potential for improvement.

In a second step, the calculation of the heating and cooling demands and the estimated consumption in the three case study buildings selected, SA, FI and CC, has been displayed in Figure 5. Results have been compared to the current Spanish standard requirements [27].

In a B4 climate zone, winter conditions are not too much severe, but just enough to make this type of buildings waste huge amounts on energy to maintain indoor comfort conditions. In every case, the lack of thermal insulation is reflected in the difference of the estimated heating demand and the standardized limit (Fig. 5; Table 3). Estimated energy consumption

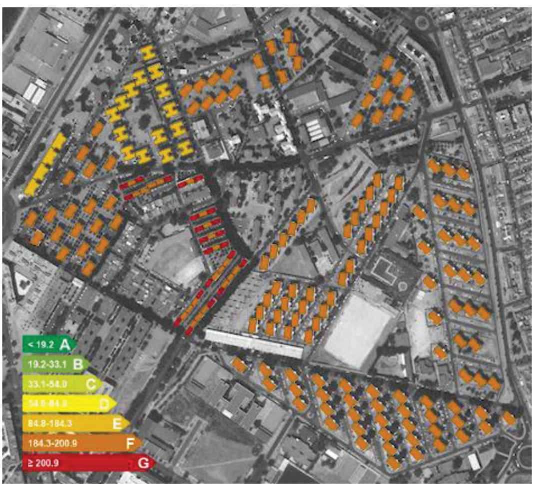

Figure 4: Energy gradation of social housing stock from the Southern district in Córdoba.

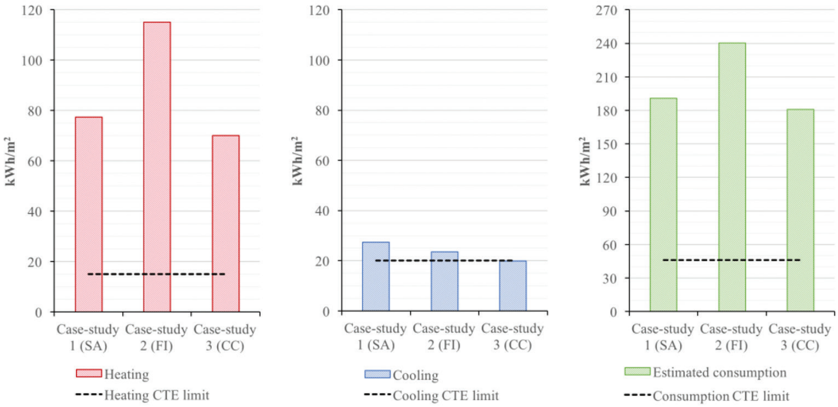

Figure 5: Heating, cooling and estimated consumption of case study buildings.

Table 3: Energy audit results.

	Case study 1 (SA)	Case study 2 (FI)	Case study 3 (CC)
Heating demand (kWh/m^2)	77.3	115.1	70
CTE heating limit demand (kWh/m^2)	15	15	15
Cooling demand (kWh/m^2)	27.4	23.6	19.9
CTE cooling limit demand (kWh/m^2)	20	20	20
Consumption (kWh/m^2)	190.7	240.4	181.0
CTE limit consumption (kWh/m^2)	46.11	46	46.03
Energy rating	E	G	E
CO_2 emissions (kg CO_2 / m²)	39.3	49.9	37.5

is far from being accomplished, with differences of 4 times the limited value (Fig. 5; Table 3). This fact was expected since these buildings were built following the previous thermal conditioning standards to NBE-CT-79 [28]. Moreover, this type of buildings from the Mediterranean area scarcely present centralized HVAC systems. Some of them hold split heat pumps in various rooms, like SA and FI, which are mainly used to combat high temperatures in summer, and inefficient electric devices, present in SA and CC, such as stoves, to sporadically warm up the indoor spaces during winter. Even if summer temperatures reach high values during the summer in a B4 climate zone, the cooling demand mostly comply with the limited standard (Fig. 5; Table 3). This may be due to the bad quality of materials and crossed natural ventilation that contributes to heat releasing during summer nights, and solar protections frequently present in Mediterranean social housing.

These energy audit results have been checked with the indoor data collected in the monitoring campaign. Figure 6 shows indoor temperature against outdoor temperature in the living room and the bedroom of case study 3, CC, during a week in winter (Fig. 6a) and a week in summer (Fig. 6b). The comparison with the comfort standard of the current Spanish regulation [29] displays that indoor temperatures fall out the comfort band, reaching

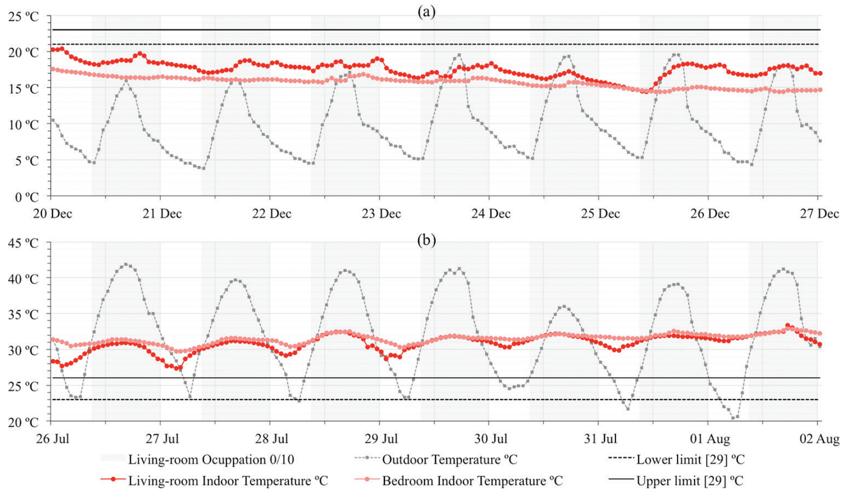

Figure 6: Indoor and outdoor temperatures registered in CC during a week. (a) Winter (from 20th to 27th December); (b) Summer (from 26th July to 2nd August).

minimum values of 14ºC in winter, while outdoor temperatures decrease up to 4ºC, and maximum values of 32ºC in summer, while outdoor temperatures increase up to 42ºC. This situation is often found in a huge amount of existing social housing that belong to the aforesaid period, where users should face bad quality conditions, almost always far from comfort.

Furthermore, the bad quality of the Mediterranean housing stock is translated to a high amount of CO_2 emissions that corresponds to a letter in the gradation scale ('E' in SA and CC; 'G' in FI) (Table 3). Regarding H2020 aims, the updating of these buildings has become a major issue to be addressed at European [30] and national levels [31].

5 CONCLUSIONS

The present work shows a protocol to gain knowledge on the current state of the existing social housing stock built from 1950 to 1980 in Córdoba, a city from the south of Spain with Mediterranean conditions. It is useful to foresee the potential of further passive energy retrofitting interventions to decrease energy consumption and improve indoor conditions.

The proposed protocol can be applied to many different scales of approach, from a dwelling scale to a territorial scale.

The methodology hereby presented displays the identification of the most common patterns within the analysed residential stock: the 'H-Block' and the 'linear block' as prototypal typologies, and 'double layer' as prototypal wall solution.

The application of the GIS database to Córdoba's social housing stock, has offered a distribution map with the energy gradation of the buildings, which show to be very deficient, graded from E to G. New energy policies may benefit from this territorial scale analysis for intervening in massive areas.

Then, three case study buildings that account for a significant percentage of the identified social dwellings in Córdoba, are selected, defined and environmentally characterized.

The lack of insulation in the thermal envelopes of the analysed buildings facilitates winter severity to strike buildings energy performance, causing a heating demand to maintain indoor comfort over 5 times the limit standard in case study SA and CC, and almost 8 times in case study FI. Moreover, the estimated consumption is around four or five times the limit value for current standards in any case. Contrary to this, summer severity does not seem to affect likewise the considered buildings, according to the cooling demand obtained with Spanish software, which shows little difference between the calculation and the limit standards. However, monitoring results show that indoor conditions fall out the steady-state band of comfort of RITE, almost all the time, in winter (differences of comfort and indoor temperature range from 1 to 6 ºC) and in summer (differences of indoor temperature and comfort range from 2 to 7 ºC). Consequently, to properly assess the quality of indoor conditions, an adaptive comfort model should be considered, as it allows for a more realistic approach.

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